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**RESEARCH CONCERNING FORECASTING ANOMALOUS
PROPAGATION AT HIGH LATITUDES**

Scientific Report No. 13

RECEPTION OF WWV IN ARCTIC DURING IONOSPHERIC DISTURBANCE

by

John R. Herman
Geoffrey E. Hill

RESEARCH AND ADVANCED DEVELOPMENT DIVISION
AVCO CORPORATION
Wilmington, Massachusetts

Technical Report
RAD-TR-61-33

Contract AF19 (604)-4092

October 1961

Prepared for

ELECTRONIC RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
AIR FORCE RESEARCH DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Bedford, Massachusetts

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ABSTRACT

Reception characteristics of WWV (from 2.5 to 25 mc/s) at five Canadian stations are shown to have regular durnal, seasonal, latitudinal, and frequency variations on ionospherically quiet days. A detailed comparison of reception quality and ionospheric parameters during a disturbed period shows that conditions on different frequencies and propagation paths are closely related to the morphology of the ionospheric disturbance. On disturbed days, reception of the lower WWV frequencies (from 2.5 to 10 mc/s) in polar latitudes is affected primarily by polar cap and auroral zone absorption, while that of the higher frequencies (from 15 to 25 mc/s) is affected primarily by depressed F2 critical frequencies and sporadic E support.

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I. INTRODUCTION

During ionospheric and geomagnetic disturbances, high frequency (hf) radio transmissions may be disrupted for several days at a time, especially in Arctic regions, although all circuits and frequencies are not usually affected simultaneously or with the same severity. With WWV reception quality data which have been obtained at five Canadian stations (Fig. 1) during the International Geophysical Year (Canadian Defence Research Board, 1957), it is now possible to study radio conditions for a wide range of frequencies (from 2.5 to 25.0 mc/s) and geographical area in the Arctic during disturbed periods.

Recently, the morphology of polar ionospheric storms has been studied with the aid of synoptic charts of ionospheric parameters (Hill, 1960), and these charts can be used to analyze communication conditions for the whole hf band at a given instant throughout the polar regions. This technique is used to show the behavior of radio reception during the major ionospheric disturbance of 12-14 September 1957.

A short summary of quiet-day reception of WWV in polar regions (Herman and Penndorf, 1961) is given to illustrate diurnal, seasonal, latitudinal, and frequency variations in signal quality along the different propagation paths.

The signals which were transmitted by WWV were aurally monitored hourly on the basis of the S-scale, which consists of the whole numbers 0-9 representing no reception to excellent quality. The S-scale, which is dependent upon such parameters as signal strength and amount of fading, is strongly subject to personal bias. Some users seem to prefer the odd numbers, while others favor the even. To minimize this odd-even choice of numbers, the 0-9 index has been compressed to only five characters from 0 to 4, representing useless, poor, fair, good, and excellent reception, respectively.

As a measure of normal conditions, the mean hourly reception for the five international geomagnetically quiet days is used because the medians have been found to be seriously depressed during months having a large number of disturbed days. Geomagnetically quiet days with abnormal polar cap absorption are excluded from the measure of normal conditions.

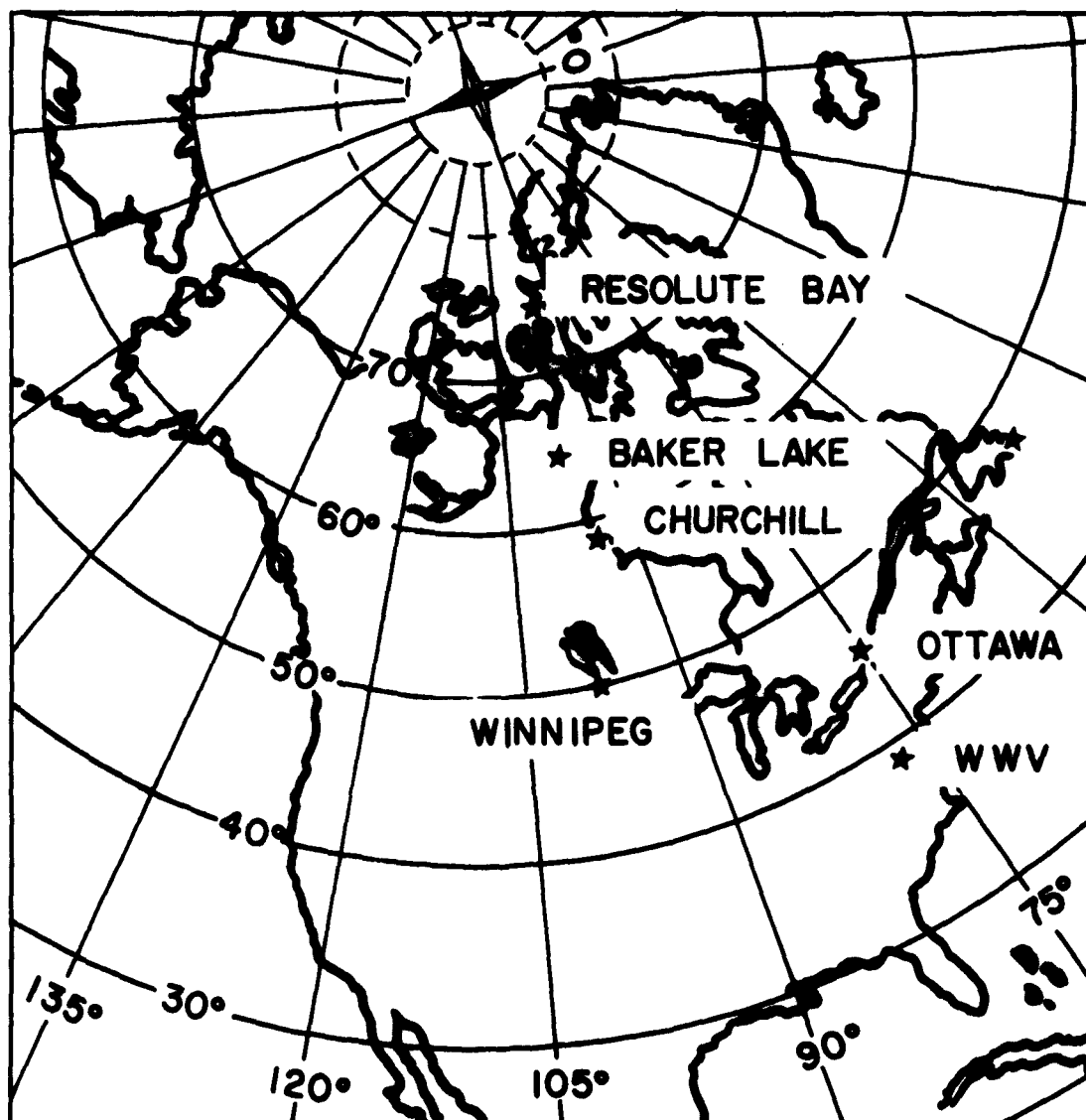


Figure 1 LOCATION OF TRANSMITTING AND RECEIVING STATIONS
61-4410

II. QUIET-DAY VARIATIONS

A. SEASONAL VARIATIONS

The hourly reception quality (0-4 scale) of each frequency at Churchill is shown in figure 2 for the months of September and December 1957, and March and June 1958, to illustrate the quiet-day reception characteristics during the different seasons. The important seasonal variations for all the stations, excepting Ottawa, can be seen from this figure. These other four stations are all more than 1000 nautical miles distant from the WWV transmitter, so that skipping is not a problem, and the differences in inverse-square distance loss between the various paths are negligible (Rawer, 1957). The controlling factor in station-to-station variations in the seasonal characteristics of reception is thus primarily the latitude dependence of the ionospheric parameters.

On 5 and 10 mc/s, the signal drops out earlier in the morning and recovers later in the evening in summer than in winter; and moreover, the trend is more pronounced with increasing latitude. This reflects the well-known solar control of D-region absorption. Studies by Davies (1960) show similar behavior in the absorption of 2 mc/s vertical incidence signals which have been measured at the same four stations.

The 20 and 25 mc/s frequencies show little solar control, and their seasonal variation follows more closely that of the F region. For example, the noontime foF2 reaches a maximum during winter in the northern latitudes, so that higher frequencies can be received. Thus, Churchill, Baker Lake, and Resolute Bay received 25 mc/s signals in December, but not at all in June. Also, much better reception of 20 mc/s was obtained during December than during June.

The data for Ottawa show no well-defined seasonal variation except for 2.5 mc/s. Above 5 mc/s, depending on frequency, the signal is either in all the time (10 and 15 mc/s) or out all the time (20 and 25 mc/s) at Ottawa. This constancy is due to the relatively short distance of about 400 nautical miles, which places Ottawa within the skip distance for 20 and 25 mc/s, and allows moderate inverse-square distance attenuation for the lower frequencies.

B. DIURNAL VARIATIONS

The diurnal pattern on the lower frequencies is characterized by a regular night reception. A fairly sharp dropout occurs shortly after sunrise, with no reception throughout the daylight hours, which is followed by a fairly quick recovery after sunset. The high frequencies behave differently. They come in shortly after sunrise, maintain good quality during the day, and decrease fairly rapidly around sunset. No reception occurs at night.

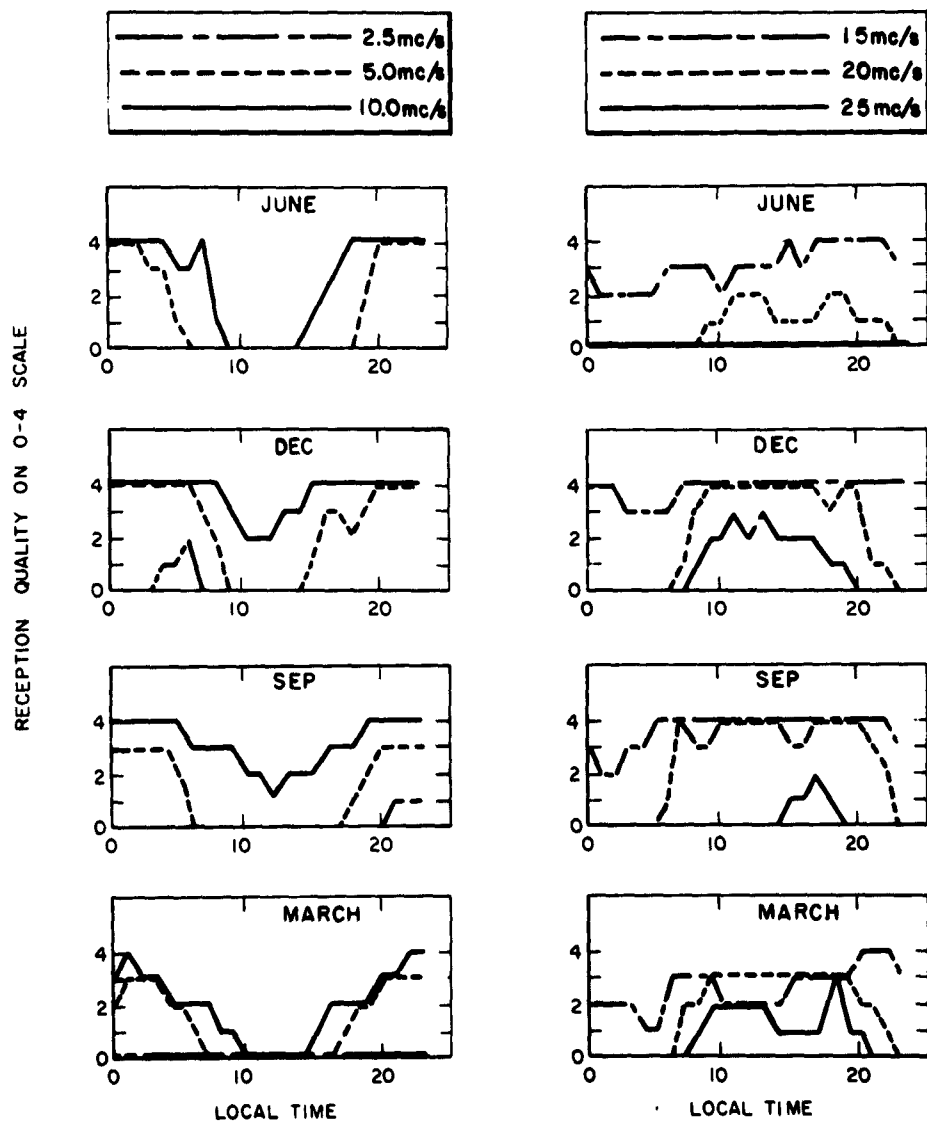


Figure 2 QUIET-DAY RECEPTION OF WWV AT CHURCHILL
61-4776

The lowest frequency of 2.5 mc/s goes out first in the morning which is followed by the 5.0, and finally, by the 10.0 mc/s signal. The evening recovery is experienced by the 10.0 mc/s signal first; this is followed by the two lower frequencies, respectively. Proceeding up the frequency scale, the intermediate frequency at 15.0 mc/s shows increased reception quality first after sunrise, then followed by the 20.0, and finally, the 25.0 mc/s signal. In the evening, dropout occurs in reverse order.*

C. LATITUDINAL VARIATIONS

For single-hop F2-layer transmission from Washington to Winnipeg, Churchill, and Baker Lake, it is found that the midpoints of the great circle paths lie within a degree or two of the 85°W meridian. In addition, using a ray-path approximation, it turns out that the WWV signals enter and leave the D layer (80 km height) at about 79° and 92°W longitude, respectively, for these stations. Thus, a station-to-station comparison will reveal only the latitude variations.

The variation with latitude of useful reception can be seen in figure 3, in which the number of hours per day of fair-to-excellent quality is plotted as a function of latitude for each frequency. In general, the frequencies from 2.5 to 10 mc/s show a decrease of number of hours of useful reception with increasing latitude, but an improvement in reception appears just north of the auroral zone for 5.0 and 10.0 mc/s.

Practically no latitude variation is evident on 15.0 mc/s as it is received nearly all of the time during quiet conditions. This frequency appears to be high enough to escape regular D-region absorption, yet low enough to avoid transmission loss due to MUF (maximum usable frequency) failure, at least during the high solar-activity years of 1957 and 1958.

*It is felt that the progressive dropout times of the different frequencies are primarily due to the changing ionospheric condition. However, the output power of WWV is not constant with frequency; and moreover, the variation of power with frequency is in the same direction as the progression of dropout time. Thus, if the power were constant with frequency, the spread between dropout times of the different frequencies would be smaller. According to the ITT Handbook (1956), the WWV transmitter power is as follows:

Frequency	Power	Frequency	Power
mc/s	kw	mc/s	kw
2.5	0.7	15	9.0
5.0	8.0	20	1.0
10.0	9.0	25	0.1

This variation in power is partially responsible for the generally better reception on 10.0 and 15.0 mc/s as compared to the other frequencies.

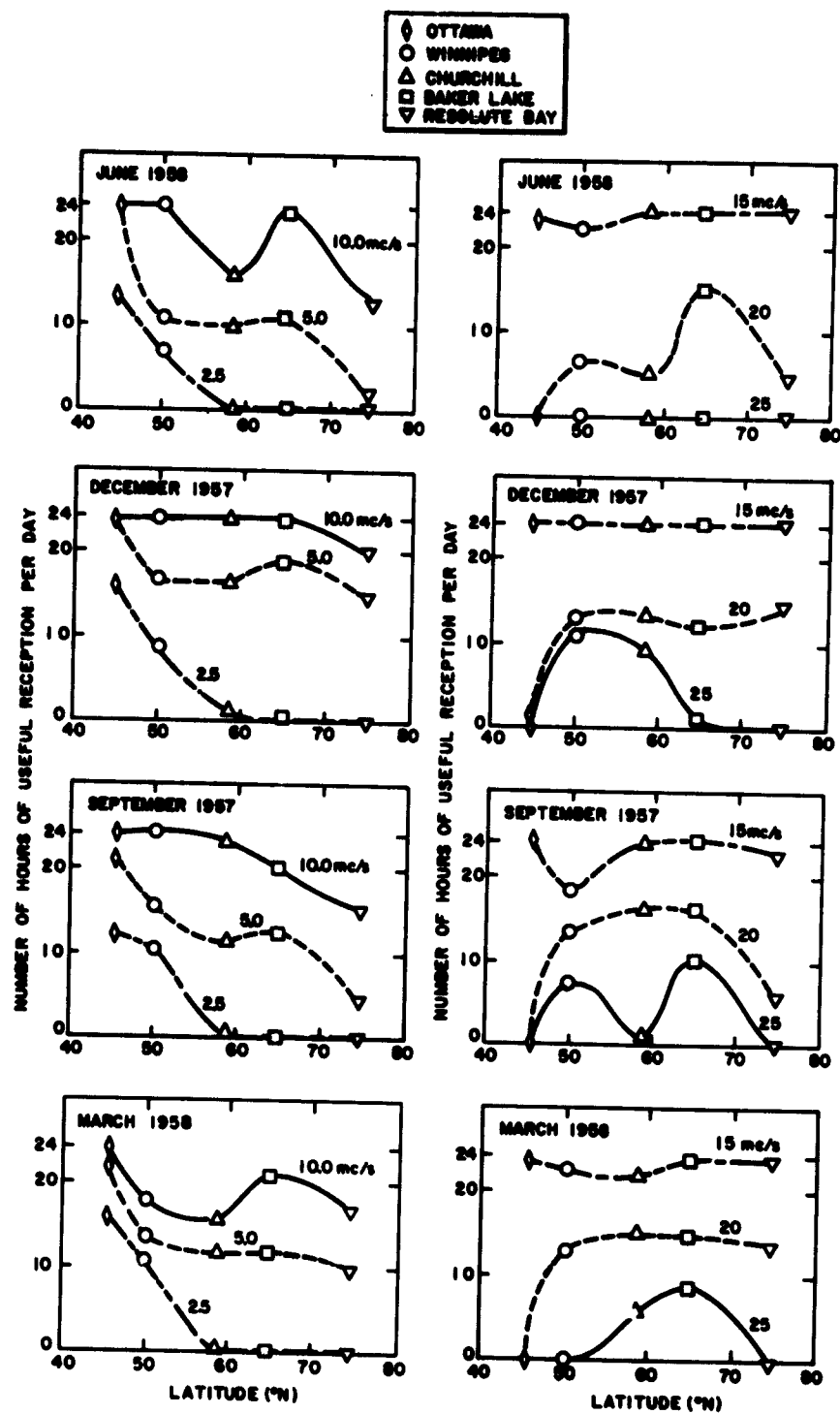


Figure 3 LATITUDE VARIATION OF QUIET-DAY WWV RECEPTION
61-4777

At the high frequencies, 20 and 25 mc/s, the controlling factor on signal reception is the F2-layer critical frequency modified by a multiplicative secant factor which depends upon the distance between stations and the F2-layer height. Most of the time at 20 mc/s, there is little latitude variation in signal reception. At 25 mc/s, there are more or less erratic latitudinal variations. Since 25 mc/s is near the MUF during the early afternoon hours, reception at this frequency is sensitive to foF2 and h'F2 variations, and so, the latitude variation is erratic.* At Ottawa, there is no reception of either 20 or 25 mc/s because the angle of incidence of the signal path with F2 layer is high.

D. VARIATIONS DURING DISTURBANCE

It has been shown in the preceding section that quiet-day reception of WWV has definite, predictable characteristics which are closely associated with ionospheric behavior. Reception quality during the severe ionospheric storm of 12-14 September 1957 will now be discussed in light of its morphology as treated by Hill (1960).

Hourly reception of the six WWV frequencies between 2.5 and 25 mc/s is plotted in figure 4 for each of the five Canadian stations during the period 12-14 September. Quiet-day variations throughout the three-day period are depicted by dashed lines in figure 4, and Greenwich Mean Time (GMT) is used for easier comparison of propagation and ionospheric variations.

The 12-14 September disturbance begins with a polar cap absorption (PCA) event at about 0600Z on 12 September, following a class III solar flare occurring at 0245Z, 11 September. Initially, the PCA is confined to the near polar region above 74°N latitude in the longitudinal sector covering the receiving stations of interest here. The geographical extent and intensity of the PCA at 0600Z, 12 September, are illustrated in the synoptic chart shown in figure 5. Subsequently, this D-region ionization (as indicated by f_{min}) spreads toward the auroral zone, and by 1500Z, 12 September, it has extended southerly to about 60°N. By the time of the sudden-commencement geomagnetic storm (SC 0046Z, 13 September), the enhanced D-region ionization has reached the auroral zone. After the SC, the f_{min} gradually returns to normal over the polar cap, while the absorption remains high in the vicinity of the auroral zone. The auroral-zone disturbance, in the form of a ring, then moves farther south, and begins breaking up about 12 hours after the SC.

Beginning with the SC, a large area of intense sporadic E (foEs) develops over Canada, moves southward, and begins dissipating near midday (SC plus 12 hours). The extent of the sporadic E disturbance at 0300Z, 13 September, some 2 hours and 15 minutes after SC, is shown in figure 6 for illustration. At about the same time, an F-layer disturbance (foF2) begins in the low latitudes and spreads over most of the northern hemisphere on 13 September. A disturbance in the F layer

*For a given distance and critical frequency, lowering the reflection height (h'F2) decreases the angle of incidence, which in turn increases the MUF.

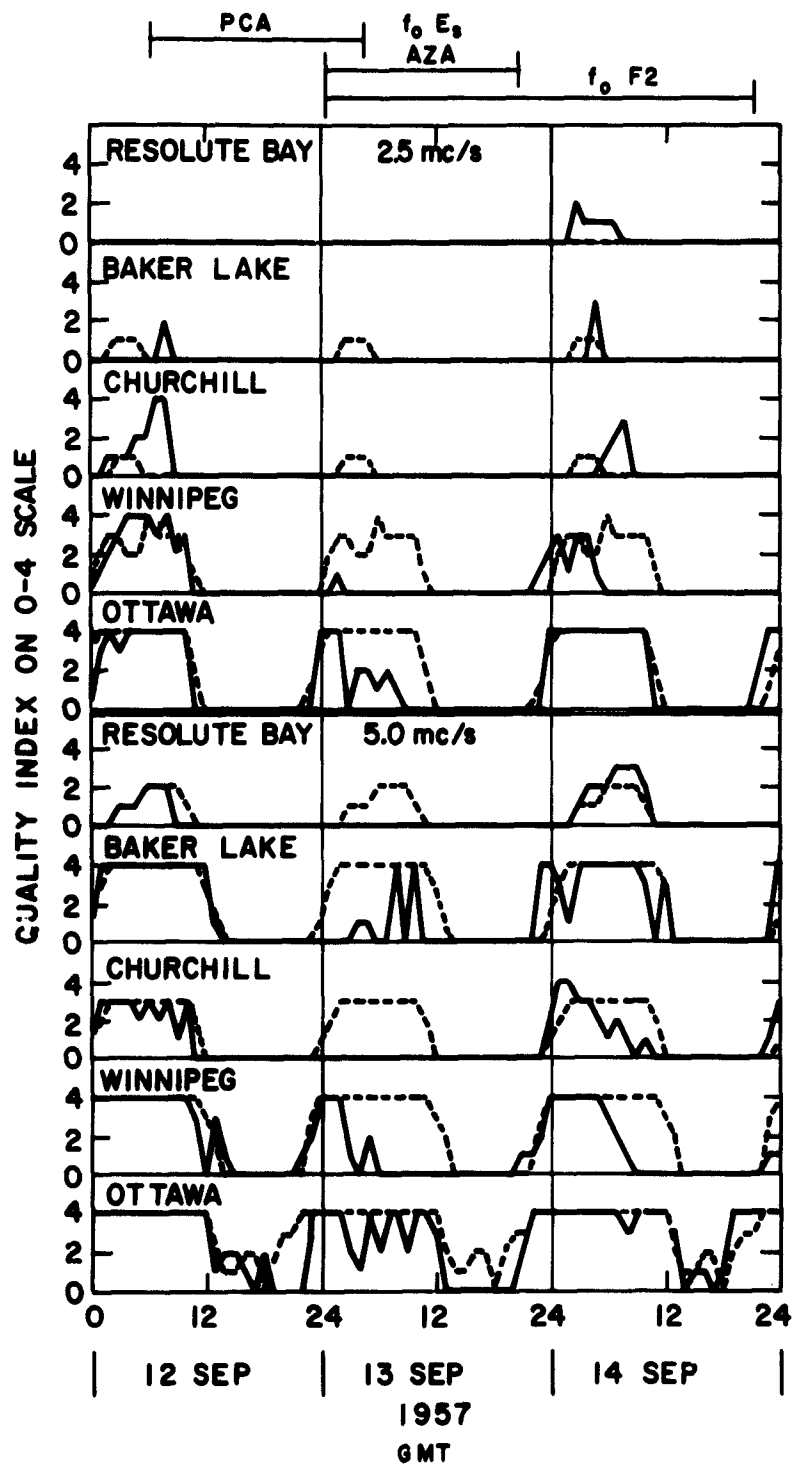


Figure 4a DISTURBED-DAY RECEPTION OF WWV ON 2.5 MC/S (TOP) AND
5.0 MC/S (BOTTOM)
61-4416

All times are GMT. Dashed line is average quiet-day reception.

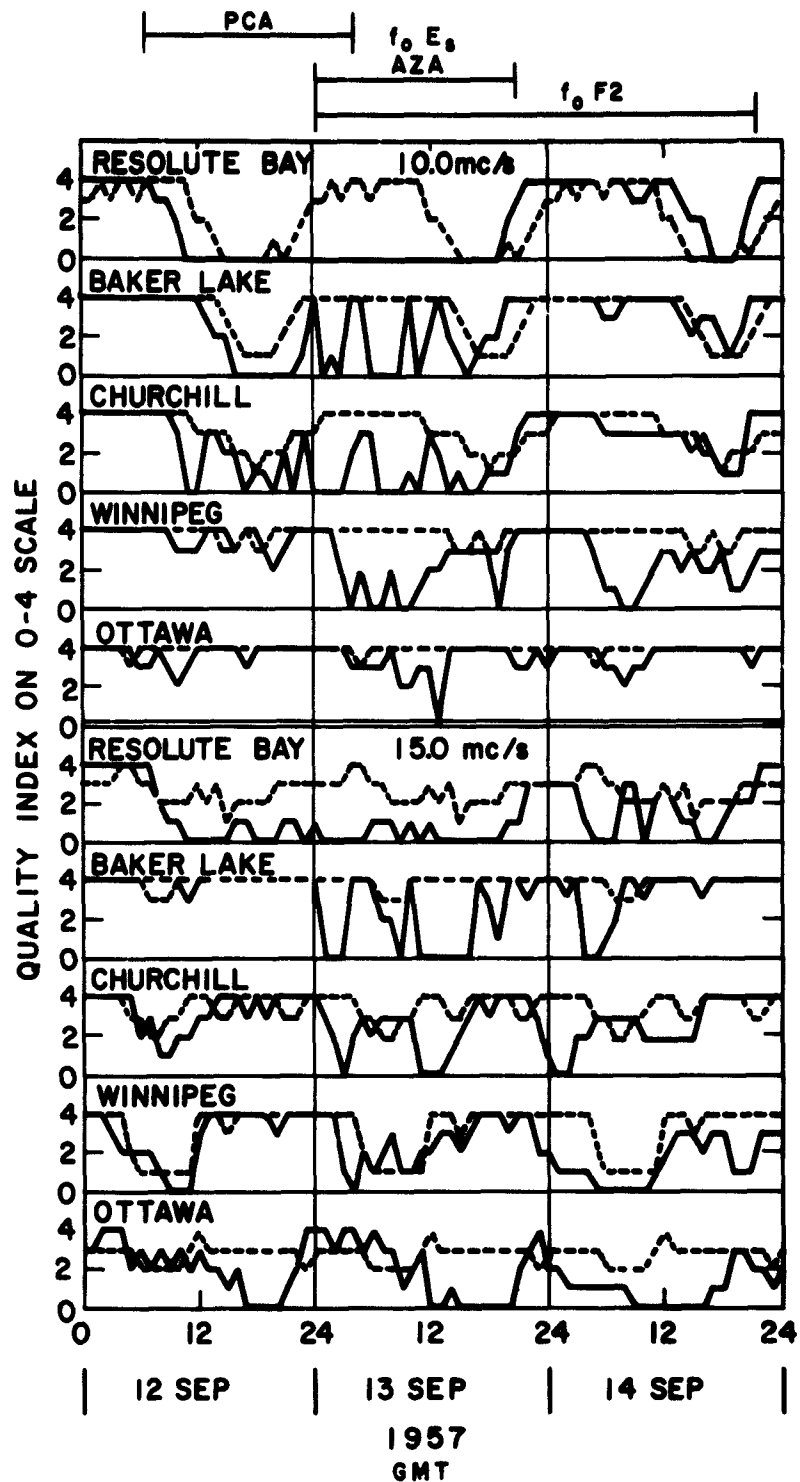


Figure 4b DISTURBED-DAY RECEPTION OF WWV ON 10 MC/S (TOP) AND 15 MC/S (BOTTOM)

61-4414

All times are GMT. Dashed line is average quiet-day reception.

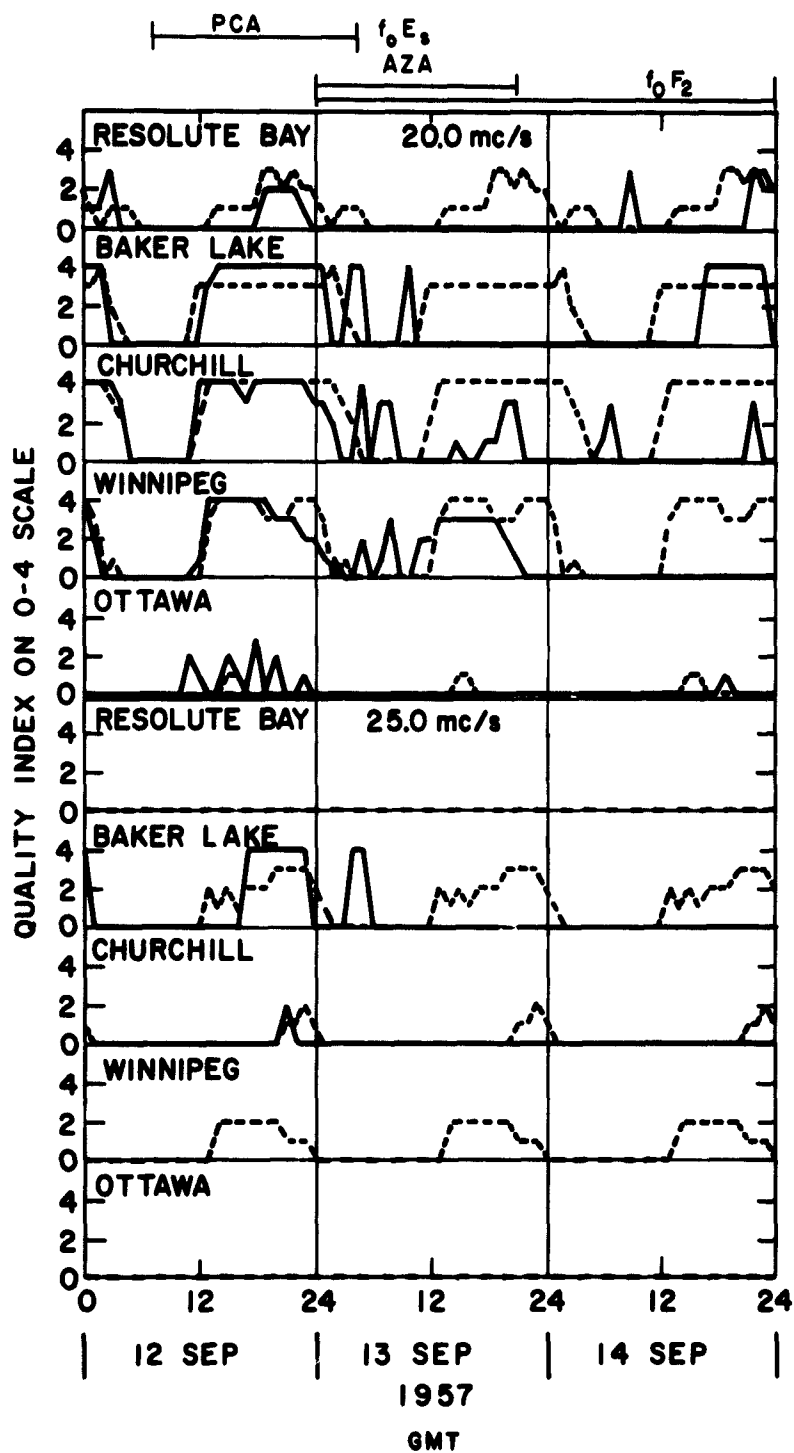


Figure 4c DISTURBED-DAY RECEPTION OF WWV ON 20 MC/S (TOP) AND 25 MC/S (BOTTOM)
61-4415

All times are GMT. Dashed line is average quiet-day reception.

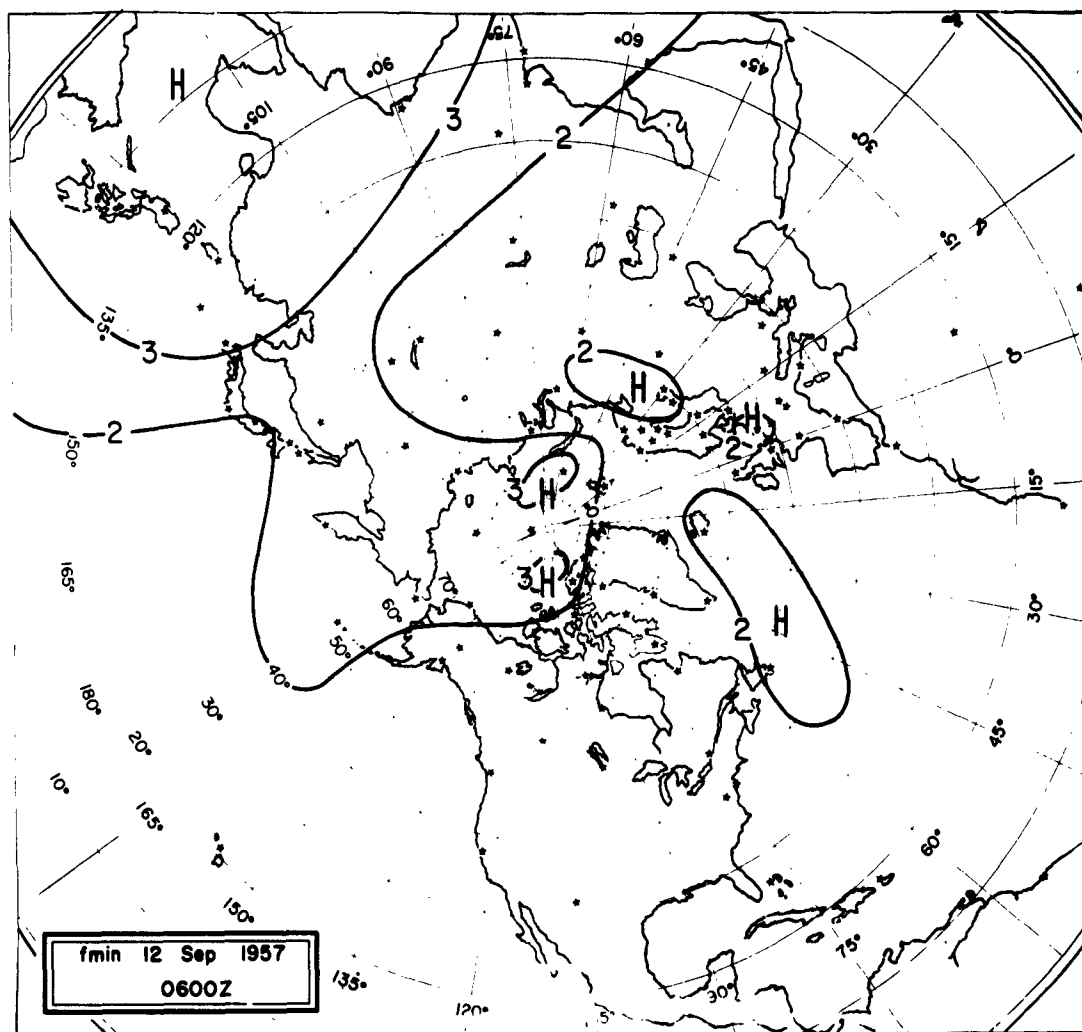


Figure 5 SYNOPTIC CHART OF POLAR CAP ABSORPTION f_{\min} AT 0600Z --
12 SEPTEMBER 1957
61-6080

The lowest frequency (f_{\min}) which is recorded by vertical incidence ionosondes is used as the measure of absorption in Hill's (1960) analysis. f_{\min} values at a given time which are recorded at stations throughout the polar region are plotted on the maps, and then, isopleths are drawn through equal values. Some smoothing is done to allow for differences in equipment characteristics between stations. Charts are constructed at three-hour intervals throughout the period of ionospheric disturbance.

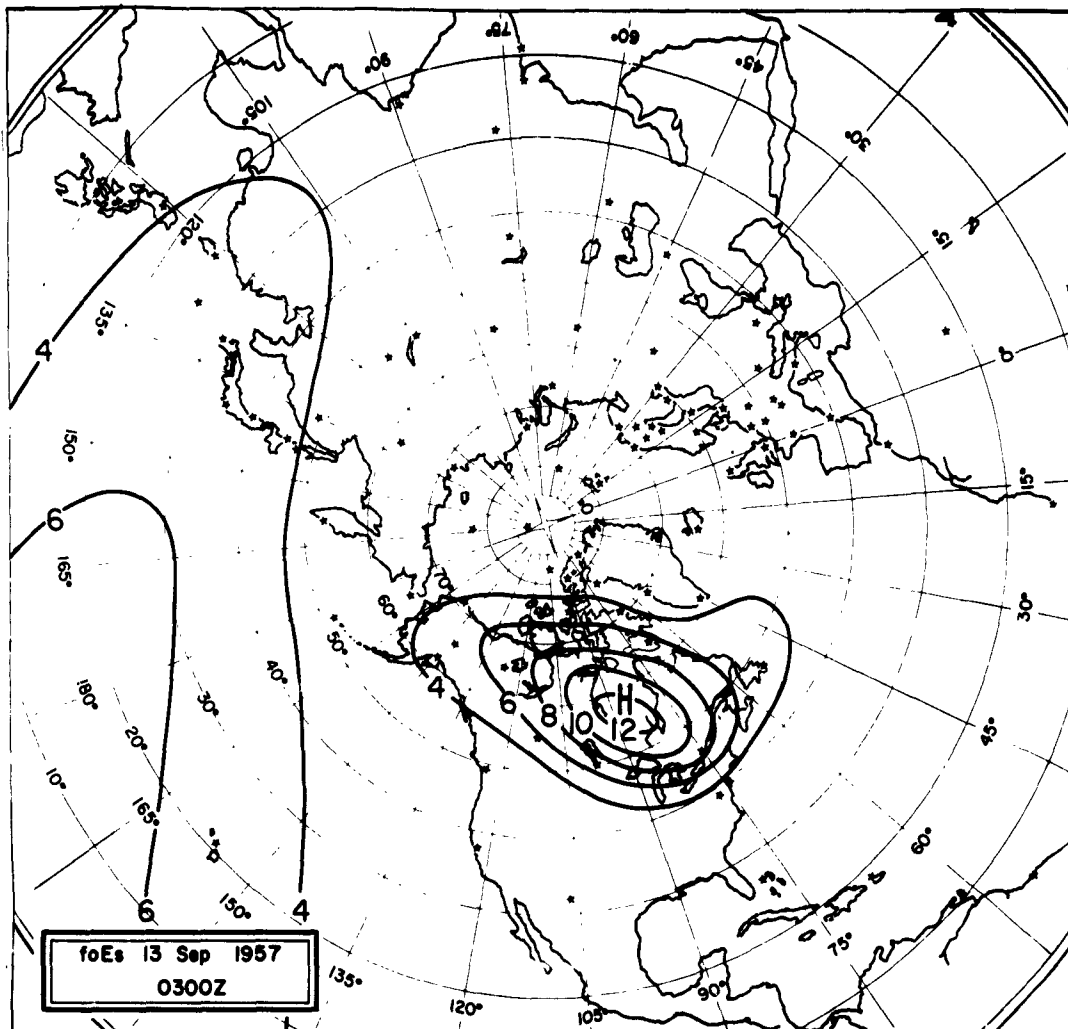


Figure 6 SYNOPTIC CHART OF foEs AT 0300Z -- 13 SEPTEMBER 1957
61-6081

Maps of the foEs disturbance, which are indicated by the highest frequency returned by the sporadic layer, are constructed at three-hour intervals throughout the disturbed period in a manner similar to the PCA charts which are illustrated in figure 5.

is typified by markedly depressed critical frequencies. That the critical frequencies are depressed in the F layer is quite evident at 1200Z, 13 September, 11 hours and 15 minutes after SC, as illustrated in figure 7. On 14 September, the foF2 pattern becomes highly disturbed, but returns to near normal by the end of the day.

The variations in WWV reception quality illustrate very graphically the effects of the disturbance on hf radio propagation, and the reason why all frequencies and circuits are not affected at the same time or with the same severity. For this purpose, it is convenient to discuss the curves of figure 4 on a day-to-day basis, and in order of increasing frequency.

1. 11 September 1957

The solar flare marking the beginning of the disturbance (0245Z) is accompanied by shortwave fadeouts in the sunlit portion of the earth, but the five circuit paths of interest here are all dark, and thus are unaffected by the flare. Reception of all six frequencies (not shown) is near normal at all stations on this day, and reception of the lower frequencies at the higher latitude stations is better than average, indicating lower than usual absorption. The day, 11 September, is the quietest of the five international geomagnetically quiet days of the month.

2. 12 September 1957

Early in the day, 12 September, conditions in the ionosphere are about normal. Polar cap absorption begins about 0600Z near the North Pole, gradually spreads southward and intensifies. By the day's end, the PCA is fully developed and extends with blackout conditions to the auroral zone. The F2 layer behaves as normal during this period.

Reception is normal on 2.5 mc/s at the two lower latitude stations (Winnipeg and Ottawa), and better than usual at Churchill. An hour of fair reception is experienced at Baker Lake at 0800Z, indicating some transient sporadic E support. The behavior of this frequency shows that the polar cap absorption has not spread very far south by 1200Z.

The effects of the PCA become apparent at Resolute Bay on 5.0 mc/s at 0900Z when the signal drops out two hours early. Reception is near normal at the other four stations during the first half of the day. At Baker Lake and Churchill, the regular evening improvement in reception is not manifested, but the 5.0 mc/s signal does return as usual at Winnipeg, in keeping with the southerly extent of the PCA.

On 10.0 mc/s, the dropout due to polar cap absorption is quite obvious at Resolute Bay, beginning at 0900Z and lasting throughout the day. The dropout begins about three hours later (1200Z) at Baker Lake, reflecting the

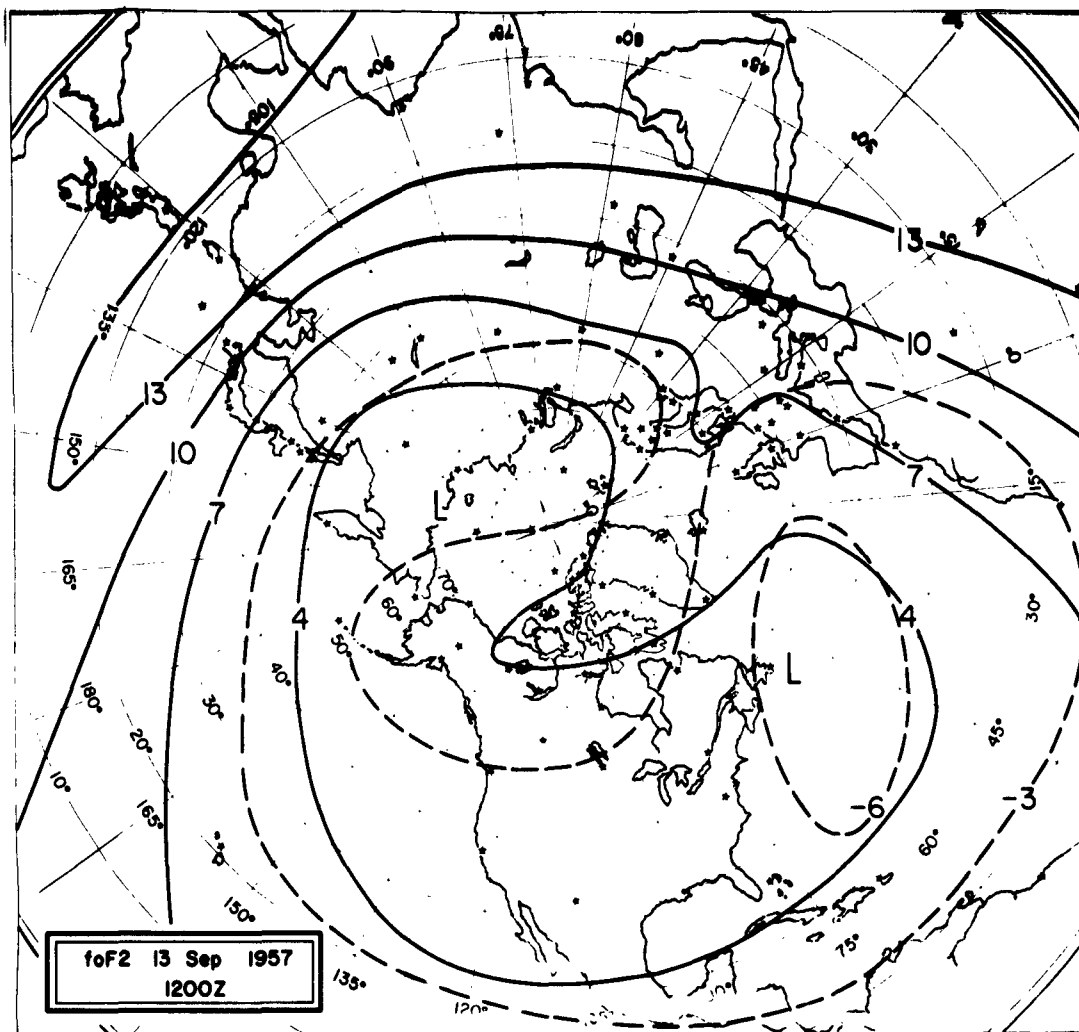


Figure 7 SYNOPTIC CHART OF foF2 AT 1200Z -- 13 SEPTEMBER 1957
61-6082

The foF2 maps are also prepared at three-hour intervals throughout the disturbance. The solid lines show normal patterns, while the dashed lines indicate the regions where foF2 is depressed 3 and 6 mc/s below the September median.

southerly movement of the PCA, and the signal remains out until 2300Z. At about 1500Z, reception at Churchill begins dropping below normal, and thereafter, on 12 September, remains depressed with wide fluctuations. This again reflects the spread of the PCA, and is in agreement with the reported time of arrival of the PCA over Churchill.*

Some high absorption farther south is apparent at Churchill on 10.0 mc/s for two hours (1100-1200Z), and to a lesser extent at Winnipeg and Ottawa. This two-hour depression does not occur at Baker Lake, indicating that the absorption region is fairly localized and is not in a position to affect the path from Washington to Baker Lake.

On 15.0 mc/s at Resolute Bay, reception drops out at 0900Z due to the PCA, and remains out for the rest of the day except for occasional reports of poor reception. Because absorption is less effective for higher frequencies, and due to the relatively higher output of WWV on this frequency (see footnote, p. 5), reception of 15.0 mc/s at Baker Lake and Winnipeg is not materially affected on 12 September. Signal quality at Churchill is somewhat depressed during the early morning hours (from 0600 to 1200Z), and reception at Ottawa is below normal from about 1200Z to 2200Z.

Reception on 20.0 mc/s at Resolute Bay is reduced about one quality point in the latter half of 12 September, and indicates the intense absorption which is associated with PCA at high latitudes. Only slight departures from normal are experienced at Baker Lake, Churchill, and Winnipeg for two reasons. First, intensity of the PCA at these lower latitudes is not sufficient to absorb 20 mc/s; and second, the foF2 disturbance has not yet begun so that no MUF failure has occurred. Fair-to-good signals were observed at Ottawa every two or three hours during the second half of 12 September; this is in agreement with the lower than usual virtual heights for the F2 layer between Washington and Ottawa.

For 25.0 mc/s, no reception is expected at Resolute Bay and Ottawa, with only five hours of poor or fair quality at Churchill. Thus, the 25.0 mc/s data are not well-suited for the present analysis, except to show occasional effects of sporadic E propagation.

3. 13 September 1957

On 13 September, large changes occur in the amount of ionization in the D, E, and F layers. The PCA reaches maximum development around 0000Z and dissipates rapidly thereafter. By 0600Z, the PCA in Canada has about ended. However, around 0300Z, auroral zone absorption occurs in connection with the geomagnetic storm. This absorption spreads southward from

*Since the maps are constructed at three-hour intervals (see Fig. 5), the precise arrival time cannot be determined; but it can be shown by interpolation that the PCA has progressed far enough south of Churchill to affect 10 mc/s after 1500Z.

the auroral zone and dissipates after 1200Z. A strong layer of sporadic E develops over Canada around 0200 or 0300Z and lasts until after 0900Z. This layer also spreads southward. The F2-layer critical frequency begins to decrease between 0300 and 0600Z. By 0900Z, the foF2 is well below its normal value and remains so throughout the day.

Thus, on 2.5 mc/s, no reception is experienced from Winnipeg northward. The usual reception quality diurnal rise takes place at Ottawa at the beginning of the day, but at 0300Z, the signal is lost because of the southward movement of the auroral zone absorption.

The 5.0 mc/s frequency is not received at all at Resolute Bay or at Churchill because of auroral zone absorption. Winnipeg begins to feel the effects of the auroral zone absorption on this frequency at 0300Z, and the signal remains out until the end of the day. The absorption is not high enough to cause complete blackout on 5.0 mc/s at Ottawa until 1300Z, some twelve hours after the sudden commencement. Recovery of the signal occurs late in the day on 13 September.

The sporadic E layer, which begins developing over Hudson Bay just after the sudden commencement, becomes intense enough to allow reception for a few hours in the forenoon at Baker Lake despite absorption. Signals evidently are being propagated between the F2 and Es layers until they penetrate to ground at the latitude of Baker Lake. No reception occurs at Churchill, however, because the sporadic layer at that latitude is too intense (foEs = 6 mc/s) for penetration. The reasonableness of this suggested propagation mode is supported by the foEs pattern at 0900Z, 13 September, as shown in figure 8.

For 10.0 mc/s at Resolute Bay, no reception is reported until 2000Z on 13 September. Before 1300Z, the auroral zone absorption is still sufficient to cause complete loss of signal, but recovery late in the day coincides with the normal diurnal variation of the 10.0 mc/s signal.

Baker Lake and Churchill experience similar behavior because of absorption, but the location and intensity of the sporadic E disturbance allows occasional reception at both stations throughout the day. Reception at Winnipeg is mostly zero between 0200 and 1200 in agreement with the southward expansion of the auroral "ring-type" absorption. After 1200Z, reception is good at Winnipeg, indicating the decrease in auroral zone absorption. At Ottawa, the signal quality is depressed for about six hours near the middle of the day.

On 15.0 mc/s, the signal recovers at about 2100Z at Resolute Bay after being out or poor all day, and as compared with 10.0 mc/s, it shows the smaller effect of absorption on the higher frequency. Reception at Baker Lake and Churchill also is better than on 10.0 mc/s, revealing the combined

effects of sporadic E support and smaller absorption. At Winnipeg, the signal reception is poor at 0300Z and 0400Z due to the southward spread of auroral zone absorption, but it is better than normal at 0700Z and 0800Z because the sporadic E layer has also spread southward following the f_{min} ring. At 1200Z, the 15.0 mc/s signal decreases at Winnipeg and drops out at Ottawa, reflecting the beginning of the foF2 disturbance in the lower latitudes.

The 20.0 mc/s signal is not received at all on 13 September at Resolute Bay. At Baker Lake and Churchill, this frequency has some Es support during the first half of the day, but the lack of reception at Baker Lake and depressed quality at Churchill after midday are due to the breakup and dissipation of the Es layer. The southward movement of Es allows sporadic reception at Winnipeg between 0400 and 1200Z, a period when the signal is not normally expected. The spread of the foF2 disturbance causes a loss of signal at Winnipeg due to MUF failure after 1900Z on the 13th, and the signal remains out for nearly forty hours. Ottawa does not receive 20.0 mc/s at all during 13 September.

On 25.0 mc/s, signal quality is zero throughout 13 September, except for two hours (0400 and 0500Z) of excellent reception at Baker Lake which can be attributed to Es support.

4. 14 September 1957

By the beginning of 14 September, the PCA has subsided and D-region ionization (f_{min} values) over the polar cap has returned to normal. Some patchy regions of high f_{min} from the breakup of the auroral ring disturbance are still in evidence at the lower latitudes. Also, by 14 September, the foF2 disturbance is fully developed. These changing ionospheric patterns are still quite evident in the WWV reception data of figure 4.

Resolute Bay, Baker Lake, and Churchill receive 2.5 and 5.0 mc/s during the night hours (from 0200 to 0800Z); reception at Ottawa is normal, but the remaining patches of high f_{min} cause a loss of signal at Winnipeg (0500).

Reception of 10.0 mc/s is normal at Resolute Bay, Baker Lake, and Churchill because 10.0 mc/s is below the MUF for these paths despite depressed F2 critical frequencies. However, on the relatively short path from Washington to Ottawa, the MUF at 0800Z drops below 10.0 mc/s, with a corresponding signal reception decrease to fair quality.

Because of the F2 disturbance, MUF failure has prevented reception of 15.0 mc/s at Ottawa until late in the day when foF2 returns to normal at the lower latitudes. Winnipeg reception is affected similarly. For the longer paths to Churchill and Baker Lake, 15.0 mc/s is below the MUF most of the day,

and complete signal outage is observed for only two hours at each of the two stations. Reception at Resolute Bay, being primarily by a two-hop (F-layer) mode, is worse than at Baker Lake and Churchill on 14 September because the higher angle of incidence which is associated with the double hop allows more frequent MUF failure.

The 20.0 mc/s frequency does not come in at all at Winnipeg on 14 September, and is not received until its expected diurnal rise time (1200Z) on the following day. As expected, 20 mc/s at all five stations is affected more seriously by MUF failure than is 15.0 mc/s.

Reception quality of all the higher frequencies is undoubtedly affected by fading due to multipath and offpath reception, and skipping, which may be introduced by rapid changes in the ionosphere. Also, the reception quality at higher latitudes, especially near the auroral zone, is seriously affected by "flutter" fading (Yeh and Villard, 1960).

5. 15 September 1957

Even on the 15th (not shown), radio conditions have not yet returned to normal throughout the geographical area under study. The lower frequencies (2.5, 5.0, and 10.0 mc/s) have essentially recovered at all stations, but the higher frequencies still reflect some residual effects of the foF2 disturbance until around 1200Z. As on the previous day, reception of 20.0 mc/s is worse than that of 15.0 mc/s.

From the foregoing step-by-step study, the general features of the disturbed radio conditions emerge as follows:

- a. The decrease in reception quality on the lower frequencies occurs first at the higher-latitude stations, and later at the more southerly stations. Normal reception returns first at the high-latitude stations and later at the stations near and south of the auroral zone. This behavior corresponds to the development of the PCA event and subsequent auroral zone absorption.
- b. Proceeding up the frequency scale, reception is less affected by absorption, as expected on the basis of magneto-ionic theory.
- c. The higher frequencies are affected first at the lowest-latitude station, and later, at the higher-latitude stations in accordance with the spread of the foF2 disturbance. Also, recovery is last at the highest latitude, where the foF2 disturbance persists longest.

d. A full day elapses between the time the lower frequencies are lost through absorption and the higher frequencies have failed because of depressed MUF. Moreover, the lower frequencies are largely recovered by the time that the foF2 pattern becomes highly disturbed. This behavior is in agreement with the morphology of the ionospheric disturbance.

e. Strong signals due to Es support are received at those stations (primarily Baker Lake and Churchill) which are properly oriented with respect to the sporadic E regions and the transmitter at Washington.

E. OUTAGE TIMES DURING DISTURBANCE

For application to practical communications into polar regions, it is instructive to consider the outage periods for all frequencies at all stations. For this purpose, the signal is considered to be "in" if the reception quality is reported as fair or better (quality index 2, 3, or 4), and "out" if the signal is poor or useless (index 1 or 0). On this basis, figure 9 has been constructed to show the outages for 12, 13, and 14 September, including the September quiet-day average reception for comparison. The presence of a horizontal line indicates that the signal is "in" on the corresponding frequency.

Considering first the quiet-day chart, it is to be noted that reception is possible on some frequency for 24 hours a day at all stations, with the lone exception of one hour (between 1500 and 1600Z) at Resolute Bay when no frequency is received. Thus, during quiet conditions, it is practically always possible to maintain hf communications into the Arctic by proper choice of operating frequency.

However, during disturbed conditions, there are periods of time in which no high frequency is usable, due to either high absorption or low MUF or a combination of both. During the particular ionospheric storm under consideration, Resolute Bay is able to receive WWV for only three hours (from 1900 to 2200Z, 12 September) during the 34-hour period from 1000Z, 12 September to 2000Z, 13 September. A second complete outage (no frequency usable) occurs at Resolute Bay on 14 September, between 1600 and 1900Z. Complete outage occurs for lesser periods of time at the other four receiving stations, as is evident from figure 9.

It is obvious that Resolute Bay suffers most from the disturbance, but it is possible that this station may have received signals from other transmitters located within the polar region, say, at Baker Lake, for example.

This speculation cannot be substantiated with the present data of course. The most remarkable feature of the information which is presented in figure 9 is that Winnipeg, Churchill, and Baker Lake reported so few hours of complete outage, considering that the 12-14 September storm was one of the most severe

during the 18 months of IGY. However, as shown in the foregoing, the different frequencies are affected at different times due to the morphological development of the ionospheric storm.

It is suggested that it would have been possible to maintain communications to the Arctic throughout the 12-14 September disturbance if a frequency-link-switching network such as that which has recently been proposed by Macdonald, Penndorf, and Hill (1961) were in operation at the time.

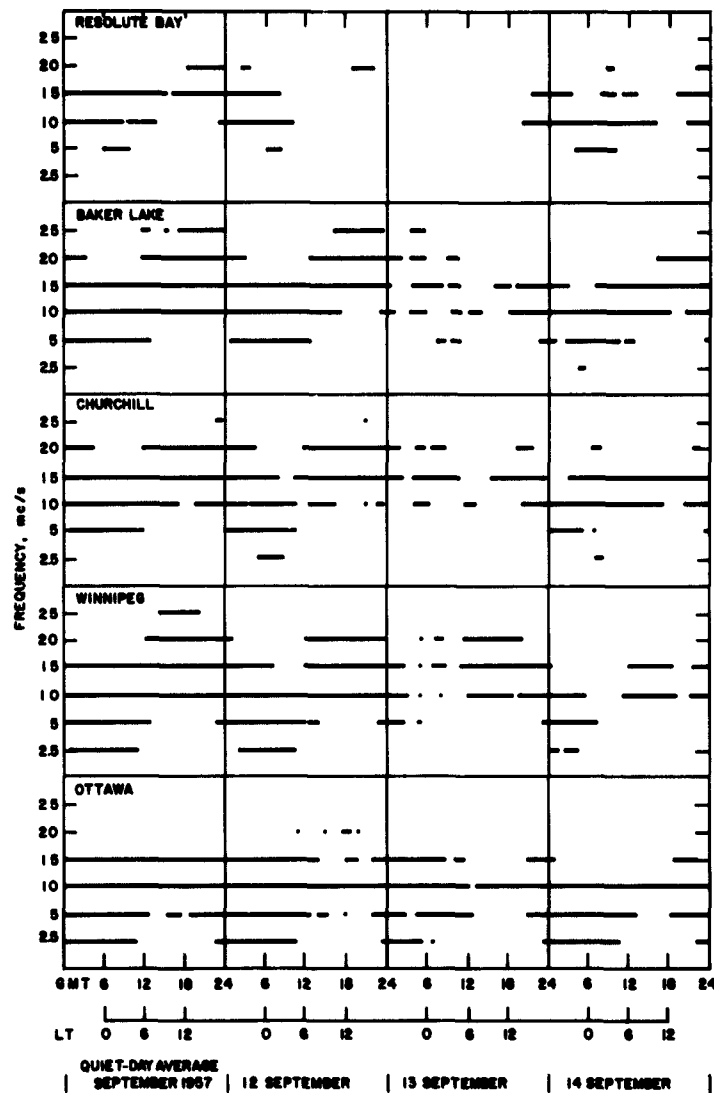


Figure 9 HOURS OF WWV RECEPTION FOR DISTURBED PERIOD FROM
12 TO 14 SEPTEMBER 1957
61-6084

Horizontal lines indicate hours that signal quality is fair or better (index 2, 3, or 4). September quiet-day average is given for comparison. For Ottawa local time (LT), subtract one hour.

III. CONCLUSIONS

During quiet conditions, reception of WWV in the polar latitudes shows definite diurnal, seasonal, and latitudinal variation characteristics. Quality of the lower-frequency signals appears to depend primarily on the absorption characteristics of the D region, whereas the behavior of the higher frequencies is closely associated with the F region.

In the high sunspot years of 1957 and 1958, 15.0 mc/s is received practically all of the time at all five stations on magnetically quiet days, and thus is the most reliable frequency to use. However, during years of low solar activity, when critical frequencies are lower, 15.0 mc/s may be too high to be the most reliable.

During the ionospheric and geomagnetic disturbance of 12-14 September 1957, reception of WWV in northern Canada closely follows the morphology of the disturbance. The lower frequencies are affected primarily by the PCA event and auroral zone absorption, while the higher frequencies reflect the storm-time behavior of the F region.

Despite the fact that the reception quality is assessed by aural monitoring, and thus subject to personal bias, the agreement between the reported data and associated ionospheric disturbance is good.

IV. ACKNOWLEDGMENTS

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V. BIBLIOGRAPHY

Canadian Defence Research Board, Canadian Ionospheric Data, Monthly (1957-1958).

Davies, K., A study of 2 mc/s ionospheric absorption measurements at high latitudes, J. Geophys. Research 65, 2285 (1960).

Herman, J. R. and R. Penndorf, Reception of WWV and WWVH in Northern Canada, AFCRL-15, Avco RAD-TR-61-5 (January 1961).

Hill, G. E., Ionospheric disturbance following a solar flare, J. Geophys. Research 65, 3183 (1960).

ITT, Handbook, Reference Data for Radio Engineers, 4th ed., International Telephone and Telegraph Corp., New York, N. Y. (1956), Chap. 1, p. 24.

Macdonald, N. J., R. Penndorf, and G. E. Hill, Predicted Performance of a High-Frequency Polar-Communication Network during an Ionospheric Storm, AFCRL-139, Avco RAD-TR-61-17 (April 1961).

Rawer, K., The Ionosphere, Ungar, New York, N. Y. (1957), 202 p.

Yeh, K. C. and O. G. Villard, Jr., Fading and attenuation of high frequency radiowaves propagated over long paths crossing the auroral, temperate, and equatorial zones, J. Atm. Terr. Phys. 17, 225 (1960).

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